TECHNICAL NOTE

D-1234

FORCE-TEST INVESTIGATION OF A MODEL OF AN AERIAL VEHICLE

SUPPORTED BY FOUR UNSHROUDED PROPELLERS

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SUMMARY

A wind-tunnel investigation has been made to study the static lon-gitudinal and lateral stability and trim characteristics of a simplified model of an aerial vehicle supported by four unshrouded propellers that were fixed with respect to the airframe so that the propeller plane of rotation was horizontal for hovering flight. The investigation showed that this unshrouded-propeller configuration required half the nose-down attitude for forward flight, experienced about half the nose-up pitching moment, and had about half the attitude instability of a shrouded-propeller configuration of the same general size. The results also showed that hor-izontal and vertical tails were required to give satisfactory stability and trim characteristics at the higher forward speeds.

INTRODUCTION

The National Aeronautics and Space Administration has investigated simplified models of a number of configurations that might be suitable for a light, general-purpose VTOL aerial vehicle. As originally visu-alized, these vehicles would be able to hover or fly forward at speeds up to about 60 knots and would carry a payload of about 1,000 pounds. Basically they consist of a body for the engine, pilot, and cargo sup-ported by two or more propellers that are either shrouded or unshrouded. The propeller plane of rotation is horizontal for hovering flight and in most cases is fixed with respect to the airframe.

The results of flight and force-test investigations of a 1/3-scale model of a vehicle having two fixed shrouded propellers are reported in references 1 and 2, and the results of a similar flight investigation of a model with four shrouded propellers are reported in reference 3. Two rather serious problems brought out in these tests which seem inher-ent in any simple shrouded-propeller configuration in forward flight are an undesirably large forward tilt angle required for trim at the higher speeds and a nose-up pitching moment which increases rapidly with

increasing forward speed. One approach to the problem of excessive tilt angles required for higher speeds is to tilt the shrouded propellers with respect to the airframe. Reference 4 gives the results of an investigation of a model that had three shrouded propellers in a triangular arrangement, one in front and two at the rear, that could be tilted with respect to the airframe.

Another approach to the problem of the undesirable pitching-moment and tilt-angle characteristics of the fixed-shrouded-propeller configurations is the use of unshrouded propellers because of the smaller pitching moment and drag resulting from translational velocity. The present investigation was therefore made with a model which had four unshrouded propellers that were fixed with respect to the airframe so that the propeller plane of rotation was horizontal for hovering flight. This paper presents the results of force tests made to obtain the forces and moments associated with the forward flight of the model and includes both longitudinal and lateral data for the basic model without tails and with horizontal and vertical tail surfaces added. Reference 5 gives the results of a flight-test investigation of this same model.

SYMBOLS

The longitudinal forces and moments were determined with respect to the wind axes and the lateral forces and moments were determined with respect to the body axes. The axes originated at the center of gravity of the model.

c   chord of horizontal tail, in.

F_L lift, lb

F_D drag, lb

F_Y side force, lb

M_Y pitching moment, ft-lb

M_X rolling moment, ft-lb

M_Z yawing moment, ft-lb

M_{Y_α} variation of pitching moment with angle of attack, ft-lb/deg

M_{Y_V} variation of pitching moment with forward speed, ft-lb/knot

F_{Y_β} variation of side force with angle of sideslip, lb/deg

M_{X_β} variation of rolling moment with angle of sideslip, ft-lb/deg

M_{Z_β} variation of yawing moment with angle of sideslip, ft-lb/deg

i_t horizontal-tail incidence, positive when trailing edge is down, deg

α angle of attack of fuselage axis relative to horizontal (tilt angle), deg

β angle of sideslip, deg

β_{Pf} propeller blade angle of front propellers measured at 0.75 of the blade radius, deg

β_{Pr} propeller blade angle of rear propellers measured at 0.75 of the blade radius, deg

MODEL

The basic model is shown in the photograph of figure 1 and in the sketch of figure 2. The model was a simplified research vehicle that was not intended to represent any specific full-scale machine but the size was such as to represent approximately a 0.3-scale model of proposed full-scale machines. The model was designed to have the same cargo box and width (with the propeller guard rings folded) as the earlier models in references 1 to 3.

The model propellers were of laminated-wood construction and for most of the tests had fixed blade angles of 13° at 0.75 of the blade radius. For one series of tests the blade angles were varied. The propellers were driven through gearboxes and interconnecting shafting by two pneumatic motors which were controlled by a throttle valve. The propeller guard rings were intended to protect the propellers without appreciably affecting the propeller characteristics and therefore were made of relatively small-diameter tubing and located with a large tip clearance.

The normal center of gravity of the model was at the center of the model and in the plane of the propellers. For one series of tests the center of gravity was moved forward 9.5 inches.

The model was tested both with its long dimension as the longitudinal axis and with its short dimension as the longitudinal axis. As shown in figures 3 and 4 these two conditions will be referred to as configurations A and B, respectively, in this report.

Figures 3 and 4 also show the horizontal and vertical tail surfaces that were added to the basic model. The horizontal tails had an airfoil shape and were mounted outboard of the propeller guard rings. The vertical tails were flat plates and were mounted under the rear half of the rear propellers.

APPARATUS AND TESTS

The model was secured, through an internal six-component strain-gage balance, to a portable sting and strut support system. The model and support assembly was then installed in the 30- by 60-foot test section of the Langley full-scale tunnel. The static longitudinal characteristics of the model were investigated by setting a tunnel speed and then covering a range of angles of attack from 0° to -30° at a constant model propeller speed. Normal force, axial force, and pitching moment were recorded at each test point. Such tests were made at each of several tunnel speeds in a range from 0 to about 30 knots. The longitudinal characteristics were investigated for the two basic configurations without tails and for the basic configurations with horizontal tail surfaces added at incidence angles from 20° to 40°. For one series of longitudinal tests with configuration A, differential propeller-blade-angle settings were used, instead of the normal 13° settings on all propellers, in order to simulate the conditions that would be needed for trim with an extreme forward location of the center of gravity. For this series of tests the forces and moments were referred to a center-of-gravity position 9.5 inches (0.34 propeller diameter) ahead of its normal position at the center of the model.

The static lateral characteristics of both configurations A and B were investigated for angles of sideslip between 20° and -20° at angles of attack between 0° and -30°. For each angle of attack investigated the tunnel speed was adjusted to give zero drag for an angle of sideslip of 0°. The effect of vertical tail surfaces mounted under the rear half of the rear propellers was also investigated. No wind-tunnel corrections have been applied to the data since the model is very small in proportion to the size of the tunnel.

RESULTS AND DISCUSSION

Since conventional aerodynamic coefficients lose their significance and tend to become infinite as the airspeed approaches zero, the results of the tests are presented in dimensional form. The model used in this investigation was constructed primarily for the flight-test investigation of reference 5. The construction techniques used were not well suited for high-power runs for extended periods of time required in force testing; therefore, the force tests were run at reduced model power. Except for the basic longitudinal data presented in figures 5 to 7, the forces, moments, and velocities presented in this report have been scaled so that, in cases in which zero net drag is indicated, the lift equals 65 pounds, the approximate flying weight of the model.

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Longitudinal Characteristics

The basic longitudinal data are presented in figures 5 to 7. Figure 5 presents the data for configuration A with and without horizontal tail surfaces and figure 6 gives the same data for configuration B. The data from the tests on configuration A without tails and with a forward center of gravity and differential propeller blade angles are presented in figure 7.

Basic configurations, no tails.- Figure 8 presents a summary of the tilt-angle α and pitching-moment variations with forward speed for the basic configurations without tails. The general trends for both configurations were the same and differed only in magnitude as would be expected from the geometry of the two configurations. Configuration A required slightly smaller forward tilt angles for trim at any given speed. Both configurations experienced an increasing nose-up pitching moment with speed up to about 18 knots where the moments leveled off to about a constant value with configuration A producing about 50 percent higher moments throughout the speed range. Speed stability M_{Y_V} (the variation of pitching moment with speed at constant tilt angle) was positive for both configurations and was highest at the lower speeds. The data show, however, that the model had attitude instability $\left(\text{positive } M_{Y_\alpha}\right)$ which increased with forward speed and was greater for configuration A than for configuration B. The flight tests of reference 5 showed that this attitude instability made the model very difficult to fly at forward speeds above about 15 knots.

Effect of horizontal tails.- In an effort to improve the stability and trim characteristics of the basic models, the horizontal tail surfaces shown in figures 3 and 4 were installed and tested at three angles

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of incidence. Figure 9 summarizes the results of these tests for con-
figuration A, and figure 10 summarizes the data for configuration B.
The characteristics of the tails were about the same for both configu-
rations. At speeds below 10 knots the tails were not very effective
because the dynamic pressure was too low. Above this speed the tail
effectiveness increased until, at speeds of 25 or 30 knots, the tails
were capable of providing both trim and angle-of-attack stability.

In general, the results show that horizontal tails having variable
incidence would be required to obtain the optimum stability and trim
throughout the speed range tested because of the large tilt angles expe-
rienced by the models. It is necessary to keep the tails at a fairly
low angle of attack relative to the local flow to keep them unstalled
so that they will have a normal lift-curve slope and therefore will have
a stabilizing influence on the model. In order to utilize the tails for
trim, however, it is necessary at the same time to keep the tails lifting
as much as possible, consistent with their being unstalled, so that they
will produce a nose-down pitching moment to counteract the nose-up
pitching moment of the basic model. Since the model had to cover an
attitude range of 30°, it was not possible to keep the tails unstalled
and lifting in a positive direction with any one angle of incidence.
For example, the data of figures 9 and 10 show that with 20° incidence
the tails were probably unstalled and made the model stable over most
of the tilt-angle range ($\alpha = -10^\circ$ to -30°), but at tilt angles greater
than -20° this tail incidence produced an additional nose-up pitching
moment. On the other hand, with 30° incidence, the tails made a greater
contribution to trim but did not make the model stable except at speeds
greater than about 22 knots.

Effect of center-of-gravity change.- One way to reduce the pitch
trim requirements in forward flight and to improve the stability char-
acteristics would be to move the center of gravity forward. This pro-
cedure, however, would result in a large unbalanced pitching moment in
hovering flight which would require that the propeller pitch be variable
through a wide range for pitch control so that the front propellers could
carry much more load than the rear propellers in hovering. The basic
data from the tests made with configuration A with the center of gravity
9.5 inches (0.34 propeller diameter) ahead of the center line of the
model and with three differential propeller-blade-angle settings are
presented in figure 7. These data are summarized in figure 11 and com-
pared with the data for the model with normal center of gravity and
fixed propeller-blade settings. By varying the blade-angle settings
it was possible to obtain trim pitching moments throughout the speed
range. Figure 11 gives the model tilt angles α required for drag trim
and the differential blade-angle settings $\beta_{Pf} - \beta_{Pr}$ used to obtain the
trim pitching moments. The settings that would be required in the range

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from hovering to 11 knots were estimated from the flight tests of reference 5. The data of figure 11 show that the large forward movement of the center of gravity resulted in attitude stability $\left(-M_{Y_\alpha}\right)$ at the higher forward speeds.

It would be expected that the large differential blade-angle settings required for hovering with a center of gravity as far forward as was tested would be inefficient from a performance standpoint. It would seem, therefore, that a combination of horizontal tails and some less forward center-of-gravity position would give the best compromise for stability, trim, and performance characteristics for a machine of this type.

Lateral Characteristics

The basic data from the lateral tests (scaled to a model weight of 65 pounds) are presented in figure 12 for configuration A and in figure 13 for configuration B with and without the vertical tails below the rear propellers. These data are summarized in figures 14 and 15 where the yawing moment, rolling moment, and side force due to sideslip $\left(M_{Z_\beta}, \ M_{X_\beta}, \ \text{and} \ F_{Y_\beta}, \ \text{respectively}\right)$ are plotted against forward speed. Also shown are the tilt angles required to achieve drag trim.

The curves of figure 14 show that configuration A without vertical tails had about neutral directional stability or at best was slightly stable at the higher speeds. The model had positive effective dihedral $\left(-M_{X_\beta}\right)$ over most of the speed range but experienced negative effective dihedral at the highest speeds tested. Adding vertical tail surfaces below the rear propellers caused a large increase in the directional stability and added an increment of negative effective dihedral.

Figure 15 shows that configuration B had the same general lateral characteristics as configuration A and differed only in the magnitude of the forces and moments. Although the trend was the same, configuration B did have positive effective dihedral throughout the test speed range.

COMPARISON OF RESULTS WITH SHROUDED-PROPELLER CONFIGURATION

Since the present investigation was undertaken partly as a result of the undesirable pitching-moment and tilt-angle characteristics of the shrouded-propeller configuration of reference 1, figure 16 is presented

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to compare the pitching-moment, tilt-angle, and attitude-stability characteristics of configuration B with those of the model of reference 1 which had two shrouded propellers in tandem. The data for both configurations were scaled to a model weight of 65 pounds. Figure 16 shows that, at any given forward speed, the present unshrouded configuration required half the tilt angle, experienced about half the nose-up pitching moment, and had about half the attitude instability of the shrouded-propeller configuration of reference 1.

<div align="center">CONCLUSIONS</div>

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On the basis of static force tests of a simplified model with four unshrouded propellers that were fixed relative to the fuselage so that the propeller plane of rotation was horizontal for hovering flight, the following conclusions are drawn:

1. The configuration having four unshrouded propellers required half the tilt angle, experienced about half the nose-up pitching moment, and had about half the attitude instability of a configuration of the same general size having two shrouded propellers.

2. Horizontal tail surfaces are required to give satisfactory stability and trim characteristics at the higher forward speeds.

3. The basic model without vertical tails was about neutrally stable directionally. Vertical tails mounted under the rear propellers made the model directionally stable.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., January 25, 1962.

REFERENCES

1. Parlett, Lysle P.: Wind-Tunnel Investigation of a Small-Scale Model of an Aerial Vehicle Supported by Ducted Fans. NASA TN D-377, 1960.

2. Parlett, Lysle P.: Stability and Control Characteristics of a Small-Scale Model of an Aerial Vehicle Supported by Two Ducted Fans. NASA TN D-920, 1961.

3. Parlett, Lysle P.: Stability and Control Characteristics of a Model of an Aerial Vehicle Supported by Four Ducted Fans. NASA TN D-937, 1961.

4. Smith, Charles C., Jr.: Wind-Tunnel Investigation of a Small-Scale Model of an Aerial Vehicle Supported by Tilting Ducted Fans. NASA TN D-409, 1960.

5. Kirby, Robert H.: Flight-Test Investigation of a Model of an Aerial Vehicle Supported by Four Unshrouded Propellers. NASA TN D-1235, 1962.

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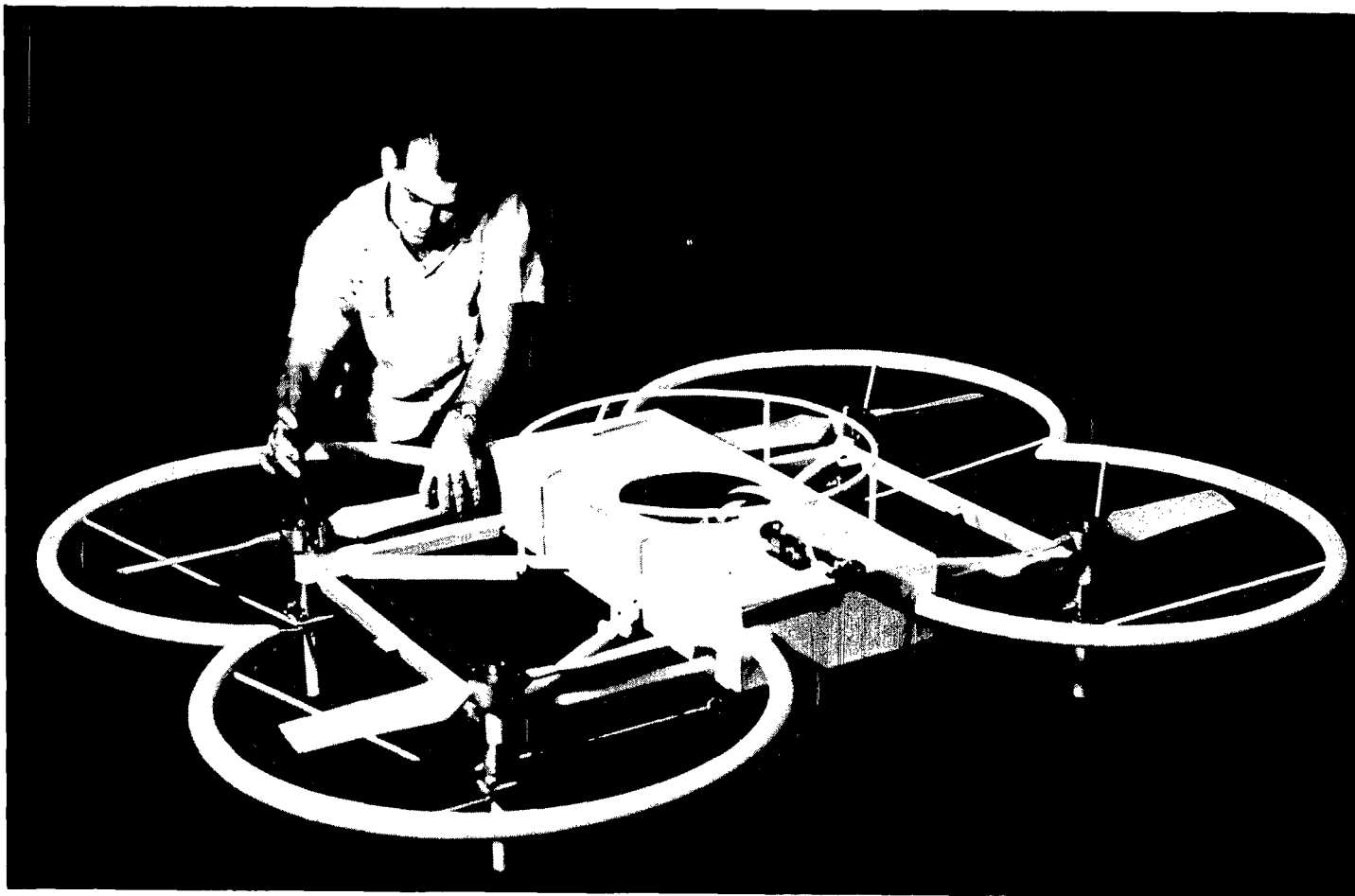
Figure 1.- Photograph of basic model.   L-59-3433

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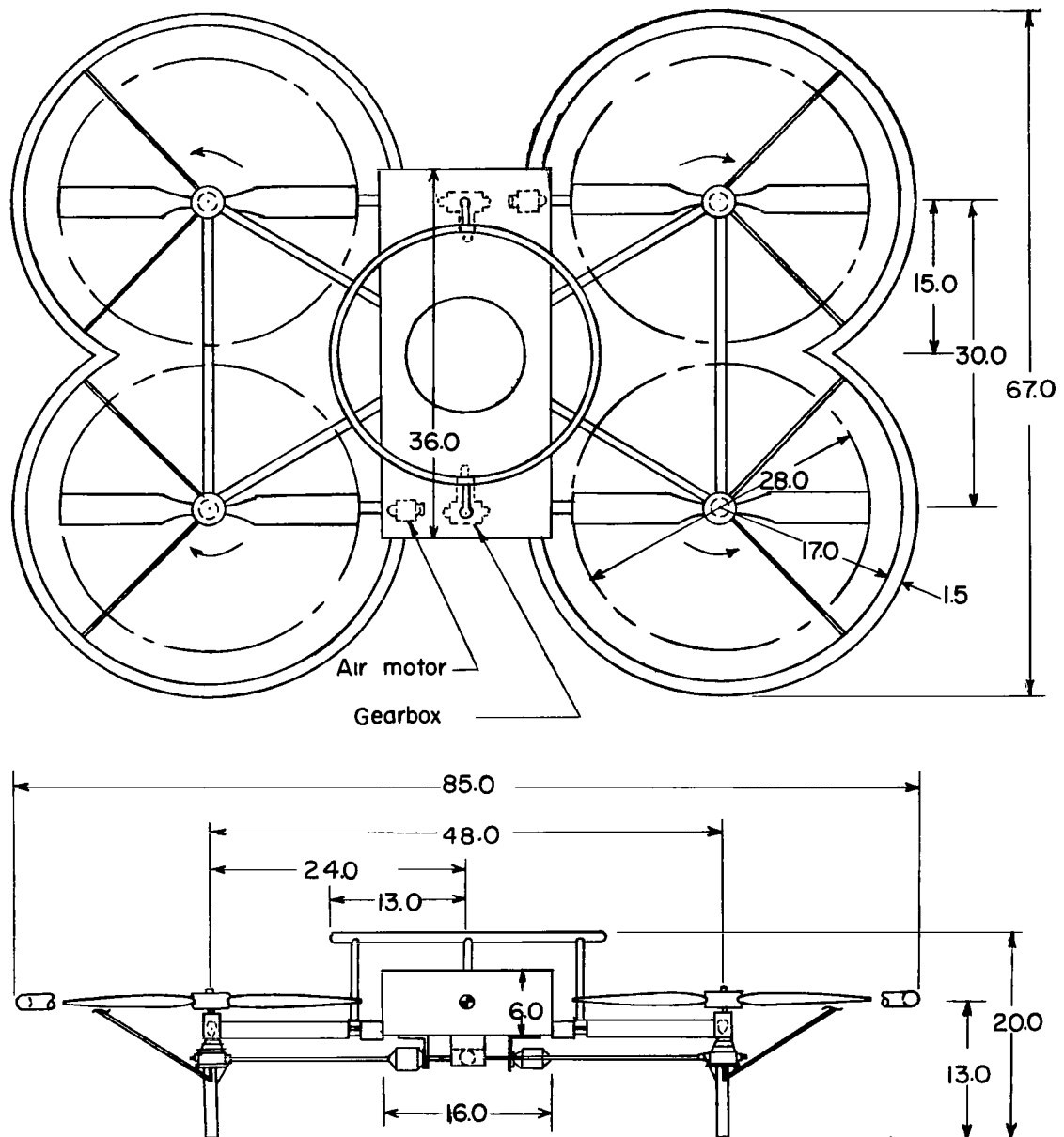
Figure 2.- Drawing of basic model. All dimensions are in inches.

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Vertical tails

15.0

18.0

24.0

36.0

Horizontal tails

$\frac{c}{4}$

7° Dihedral

9.0

9.0

Vertical tails

19.0

i_t

Wind direction
Configuration A
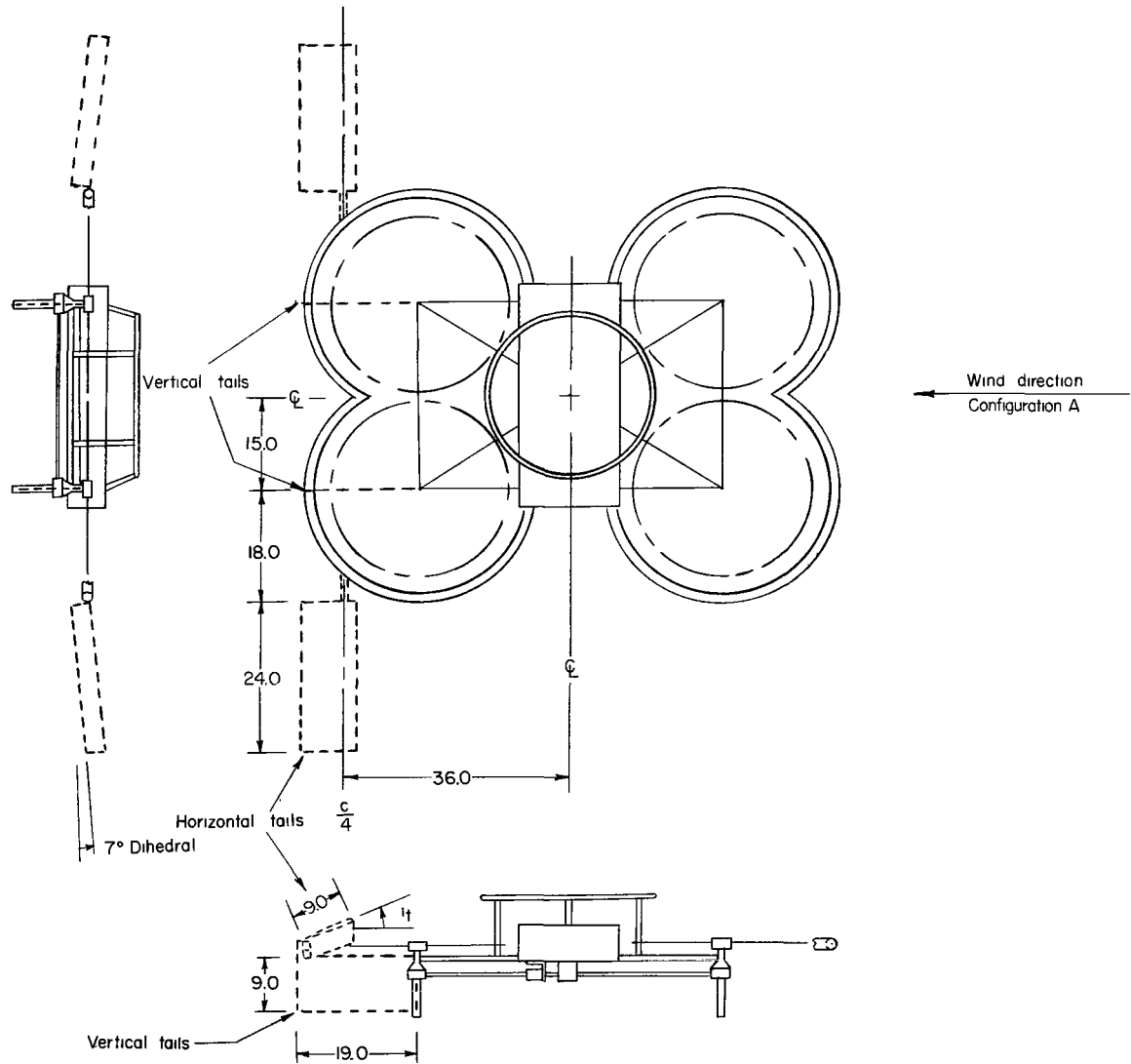
Figure 3.- Sketch of configuration A with horizontal and vertical
tails indicated by dashed lines.

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Vertical tails

Wind direction
Configuration B

C

24.0

18.0

24.0

27.0

c/4

7° Dihedral

Horizontal tails

9.0

l_t

9.0

Vertical tails

19.0
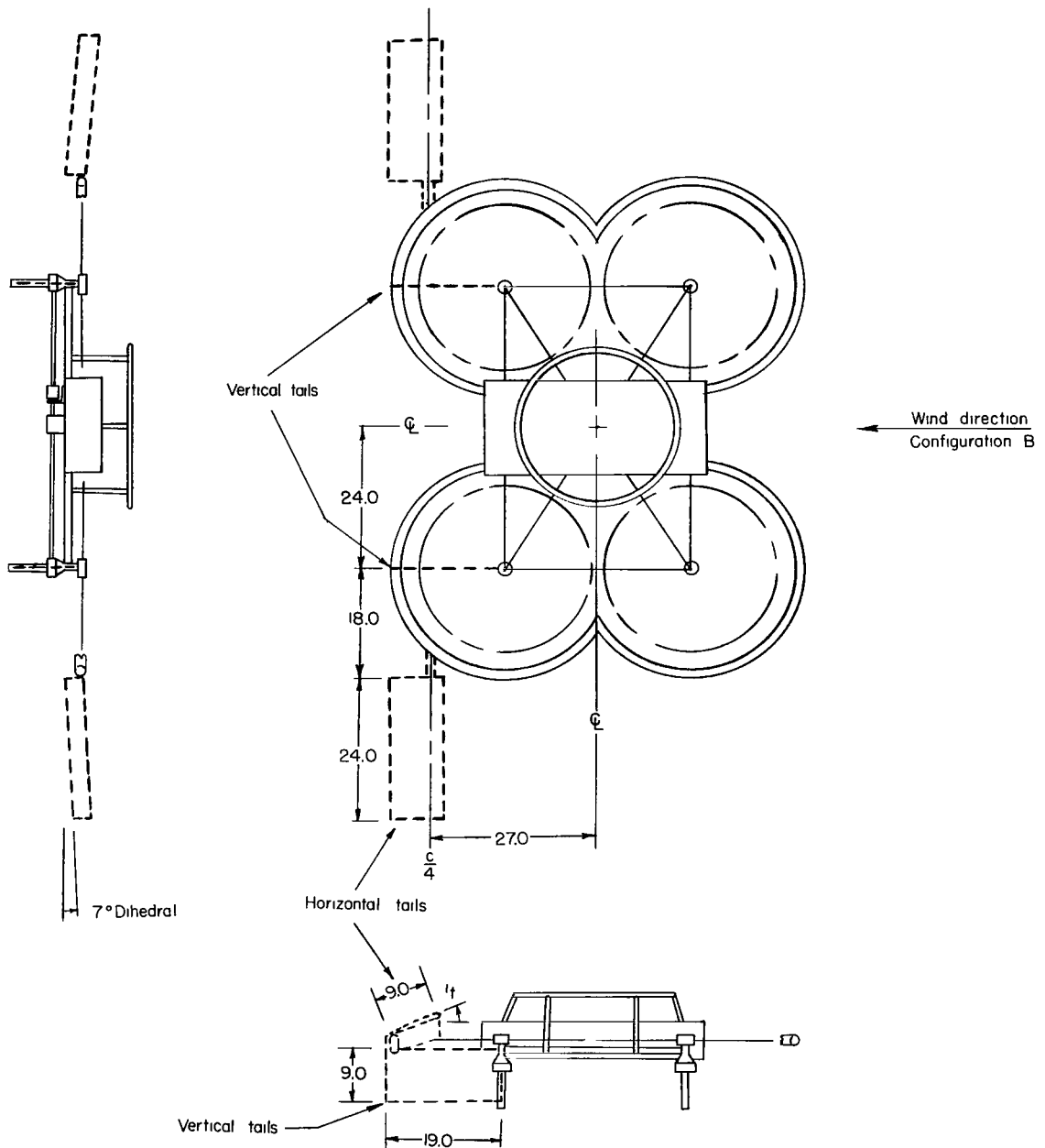
Figure 4.- Sketch of configuration B with horizontal and vertical
tails indicated by dashed lines.

(a) No tails.
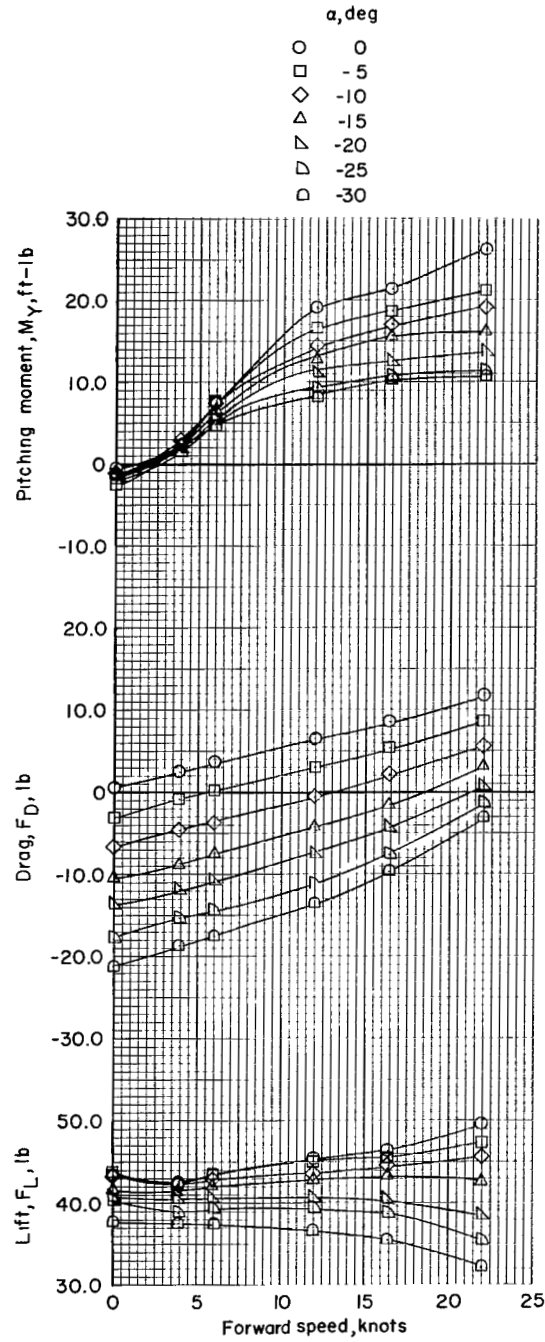
Figure 5.- Basic longitudinal data, configuration A.

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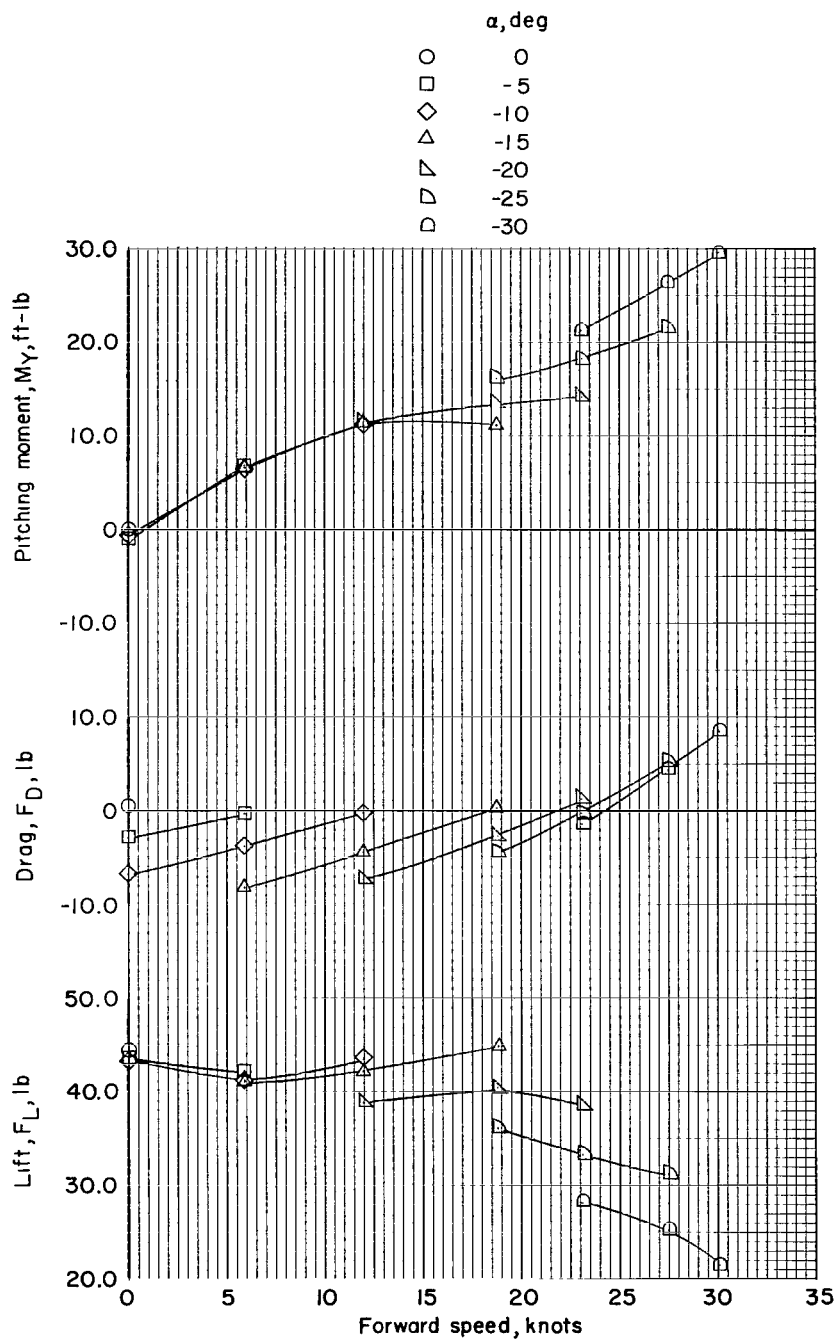
(b) Horizontal tails on, $i_t = 20^o$.

Figure 5.- Continued.

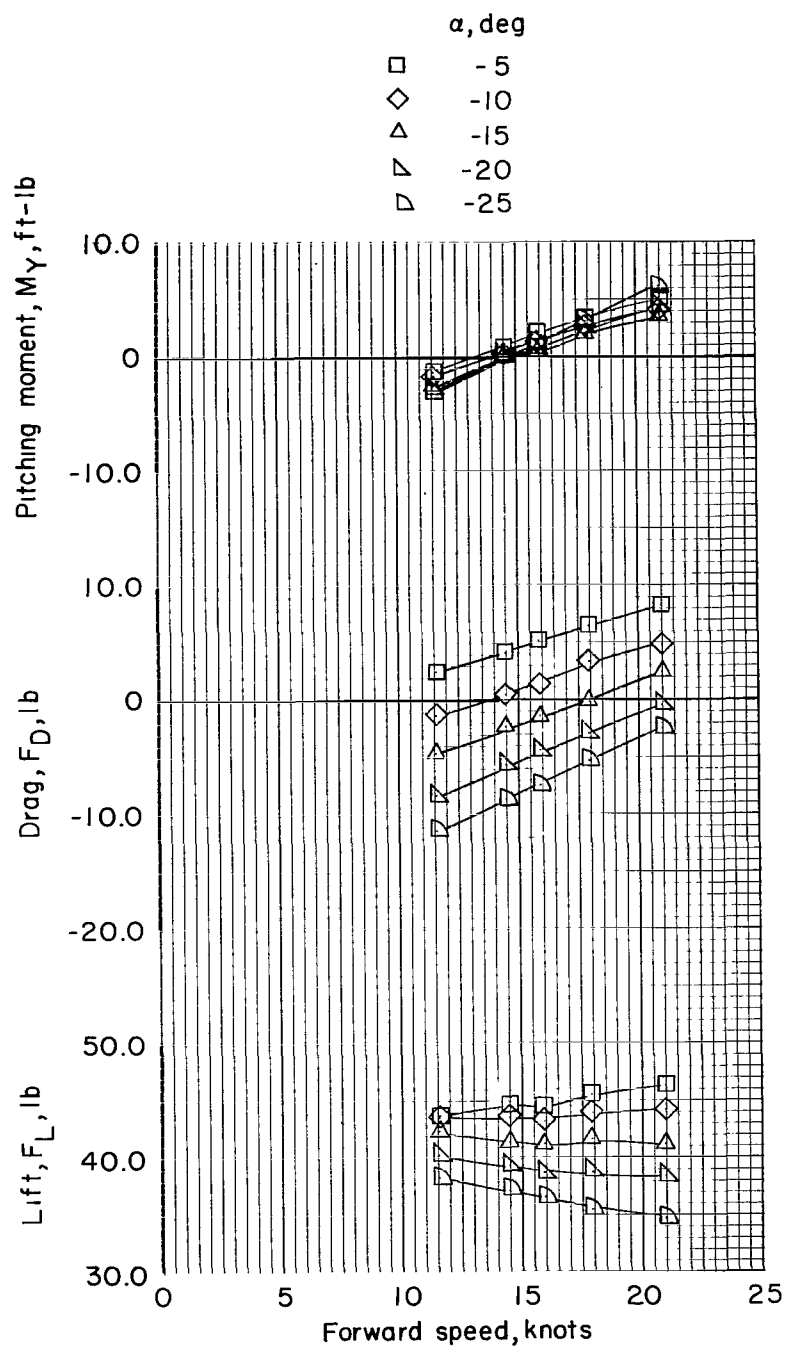(c) Horizontal tails on, $i_t = 30^o$.

Figure 5.- Continued.

(d) Horizontal tails on, $i_t = 40°$.

Figure 5.- Concluded.

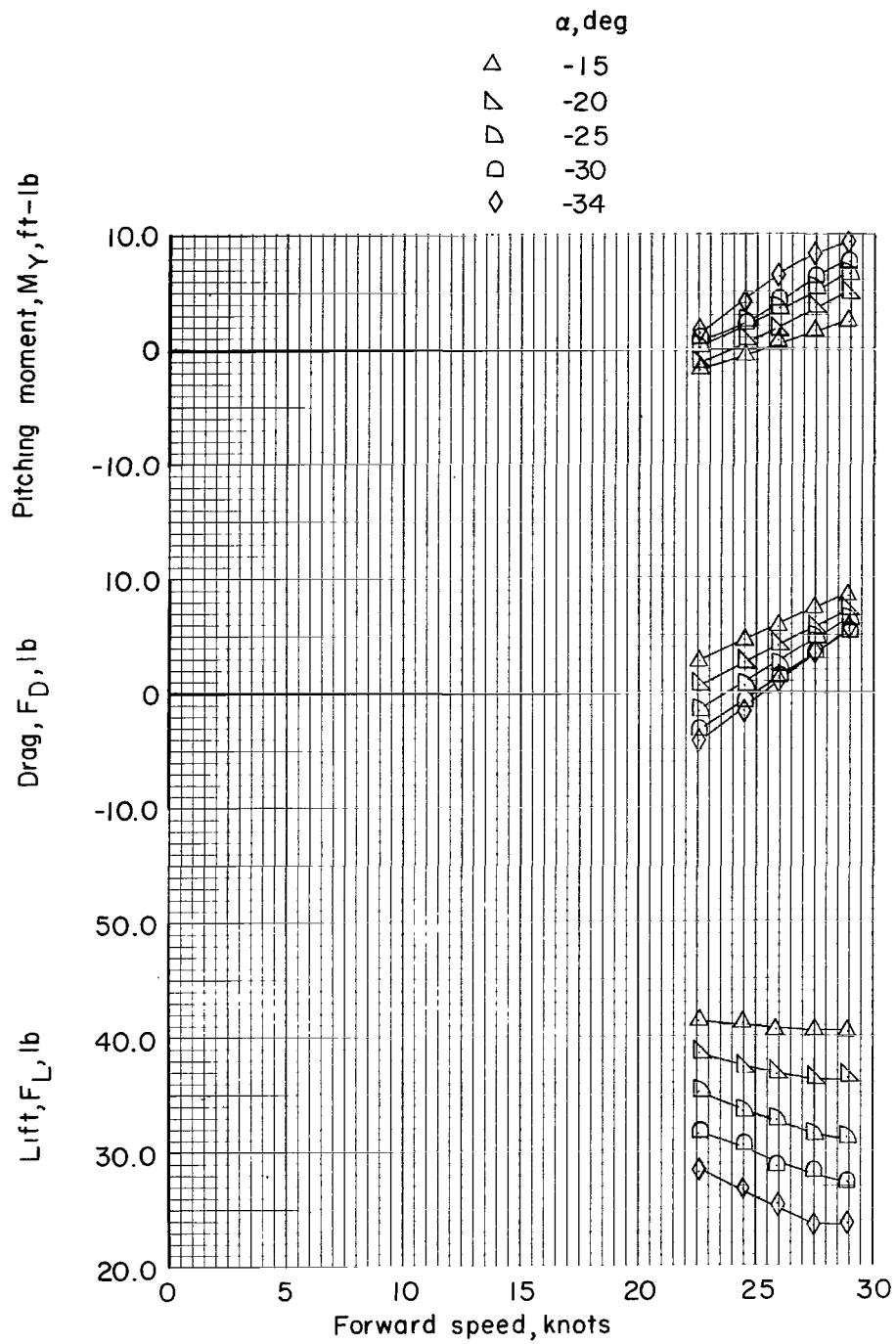(a) No tails.
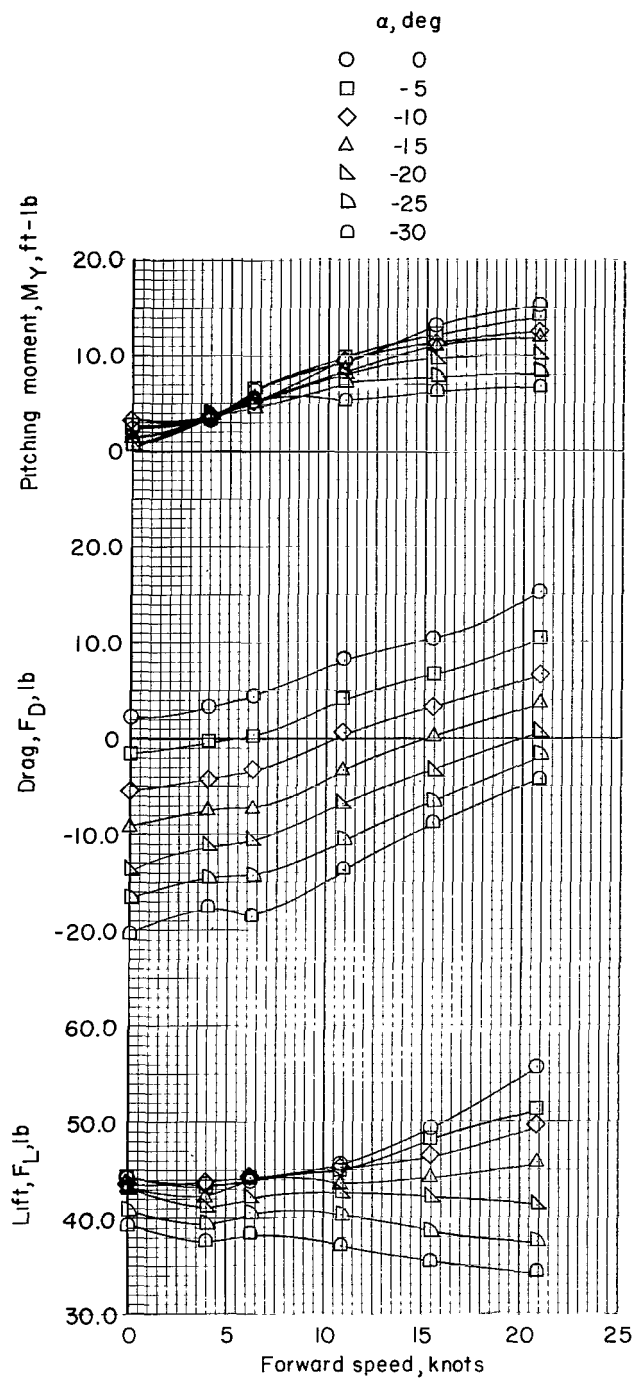
Figure 6.- Basic longitudinal data, configuration B.

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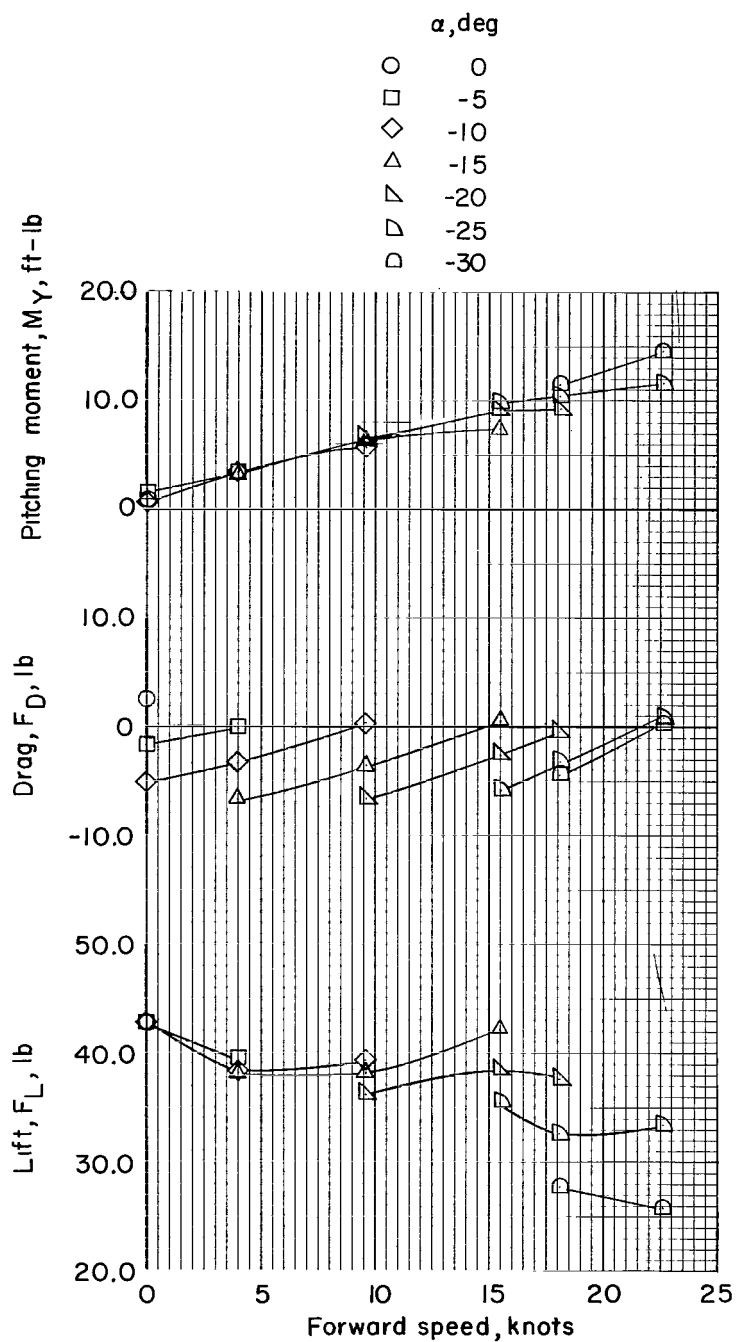
(b) Horizontal tails on, $i_t = 20^o$.
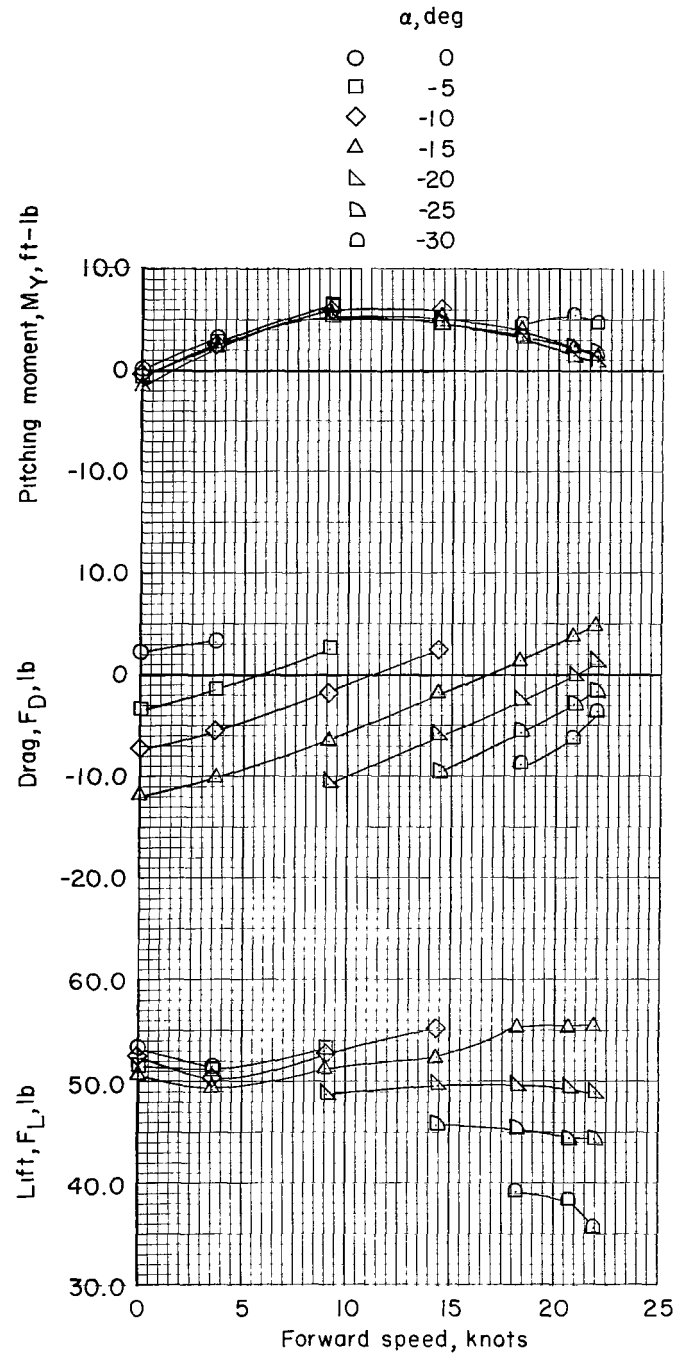
Figure 6.- Continued.

(c) Horizontal tails on, $i_t = 30°$.

Figure 6.- Continued.

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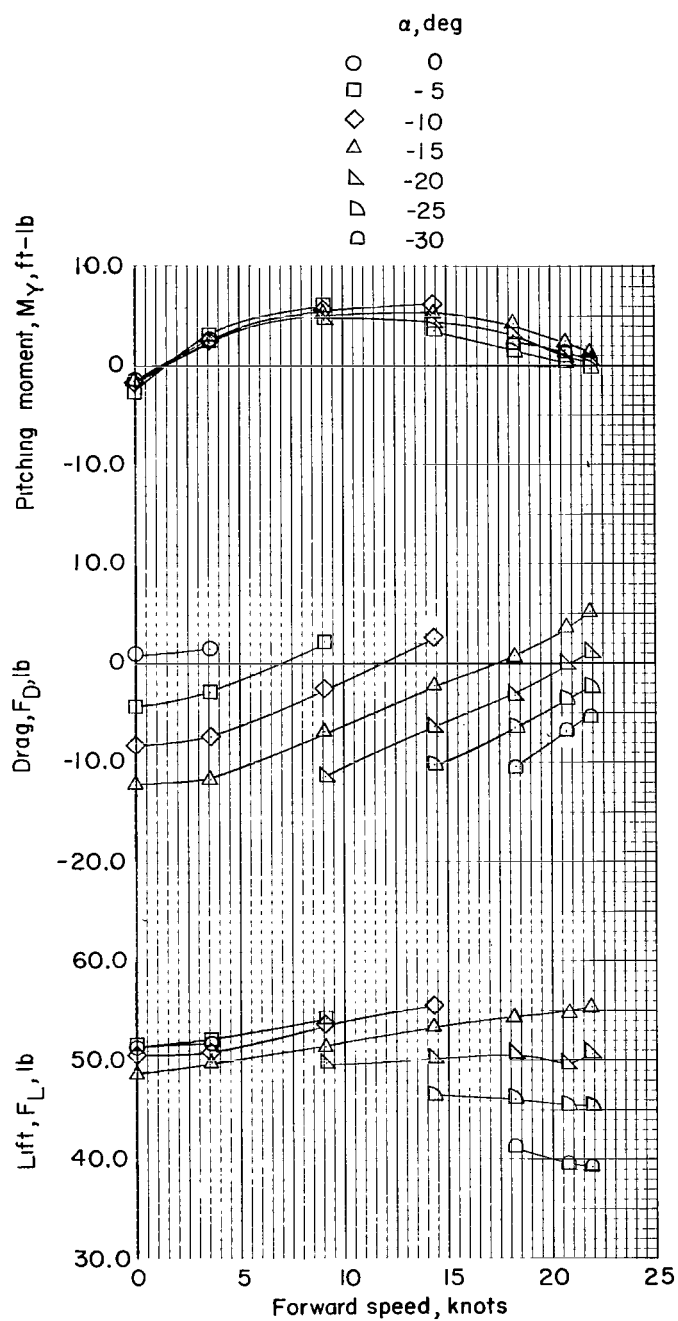
(d) Horizontal tails on, $i_t = 40°$.

Figure 6.- Concluded.
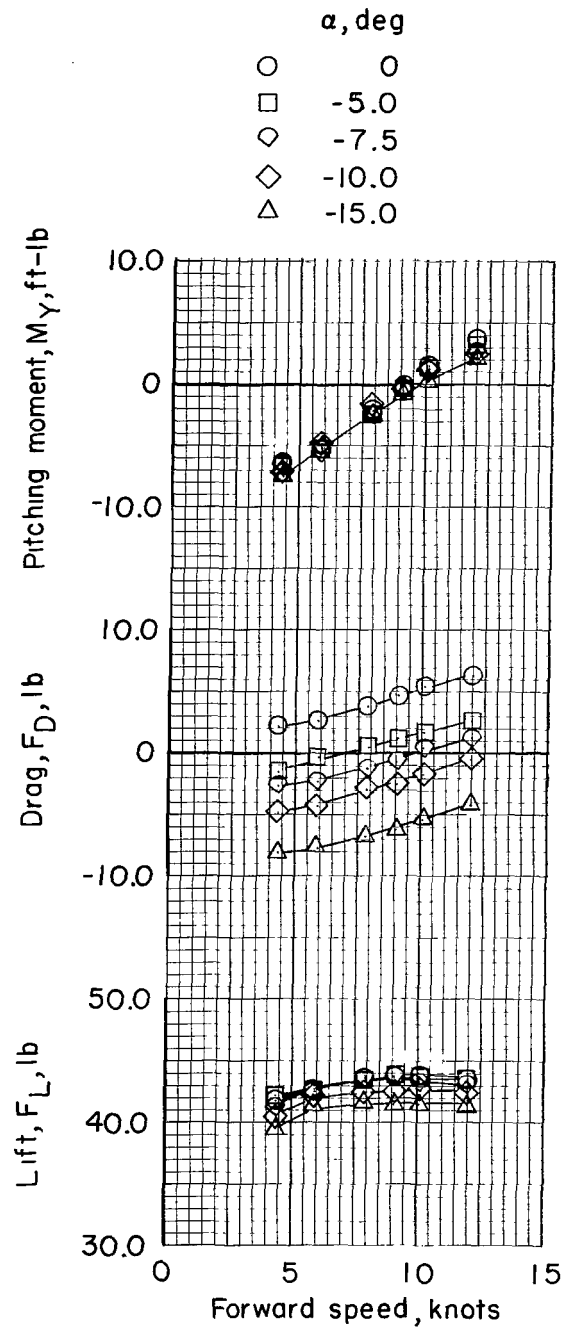
(a) $\beta_{Pf} = 17°$; $\beta_{Pr} = 9°$.

Figure 7.- Basic longitudinal data for configuration A without tails and with forward center of gravity.

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α, deg

□ -5
◇ -10
△ -15
◁ -20
◁ -25

Pitching moment, M_Y, ft-lb

10.0

0

-10.0

Drag, F_D, lb

10.0

0

-10.0

-20.0

Lift, F_L, lb

50.0

40.0

30.0

0   5   10   15   20   25

Forward speed, knots

(b) $\beta_{Pf} = 16^o$; $\beta_{Pr} = 10^o$.

Figure 7.- Continued.

(c) $\beta_{Pf} = 15^\circ$; $\beta_{Pr} = 11^\circ$.

Figure 7.- Concluded.

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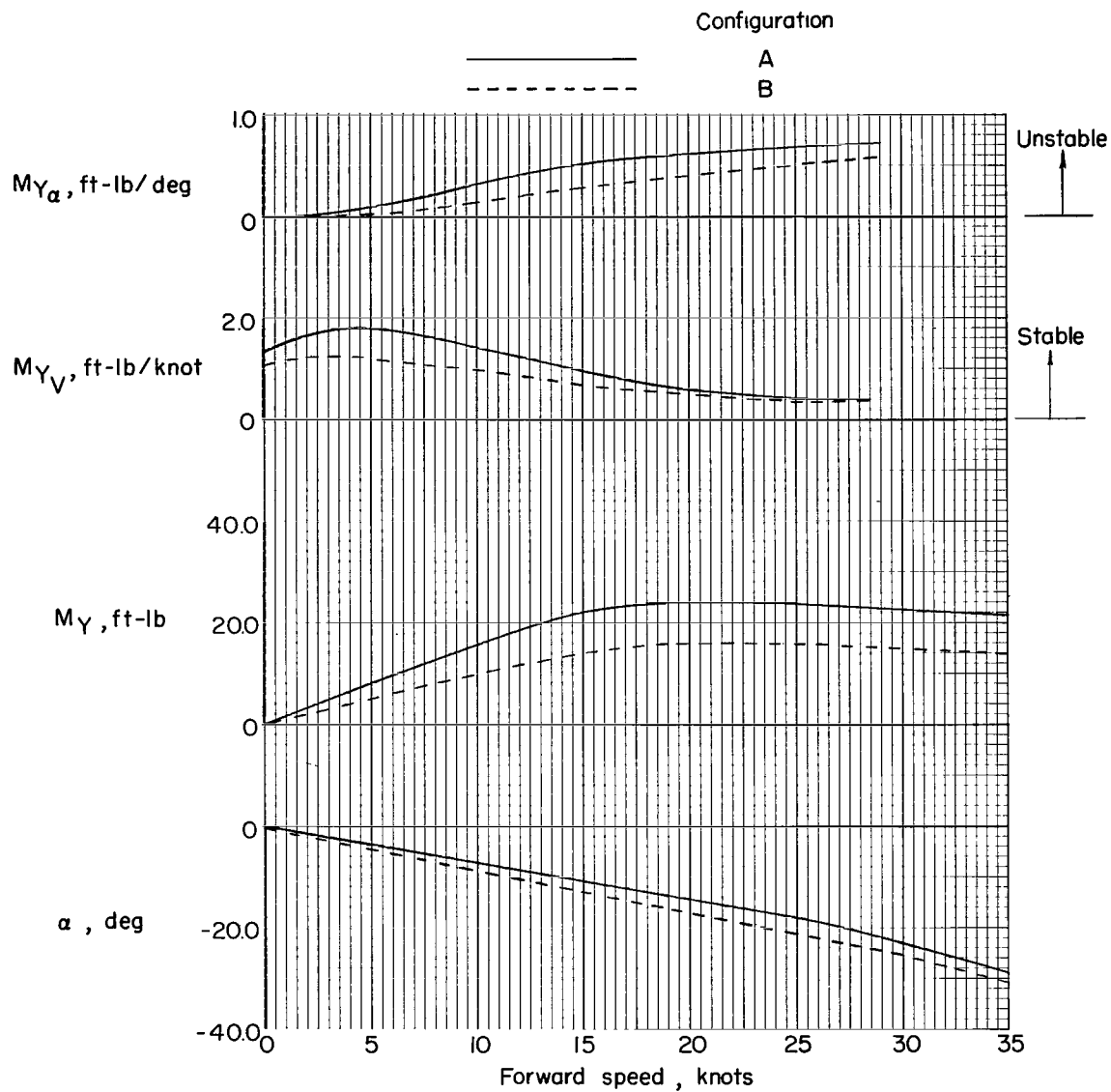
Figure 8.- Variation of longitudinal characteristics with forward speed.   Basic configuration, no tails; drag = 0.
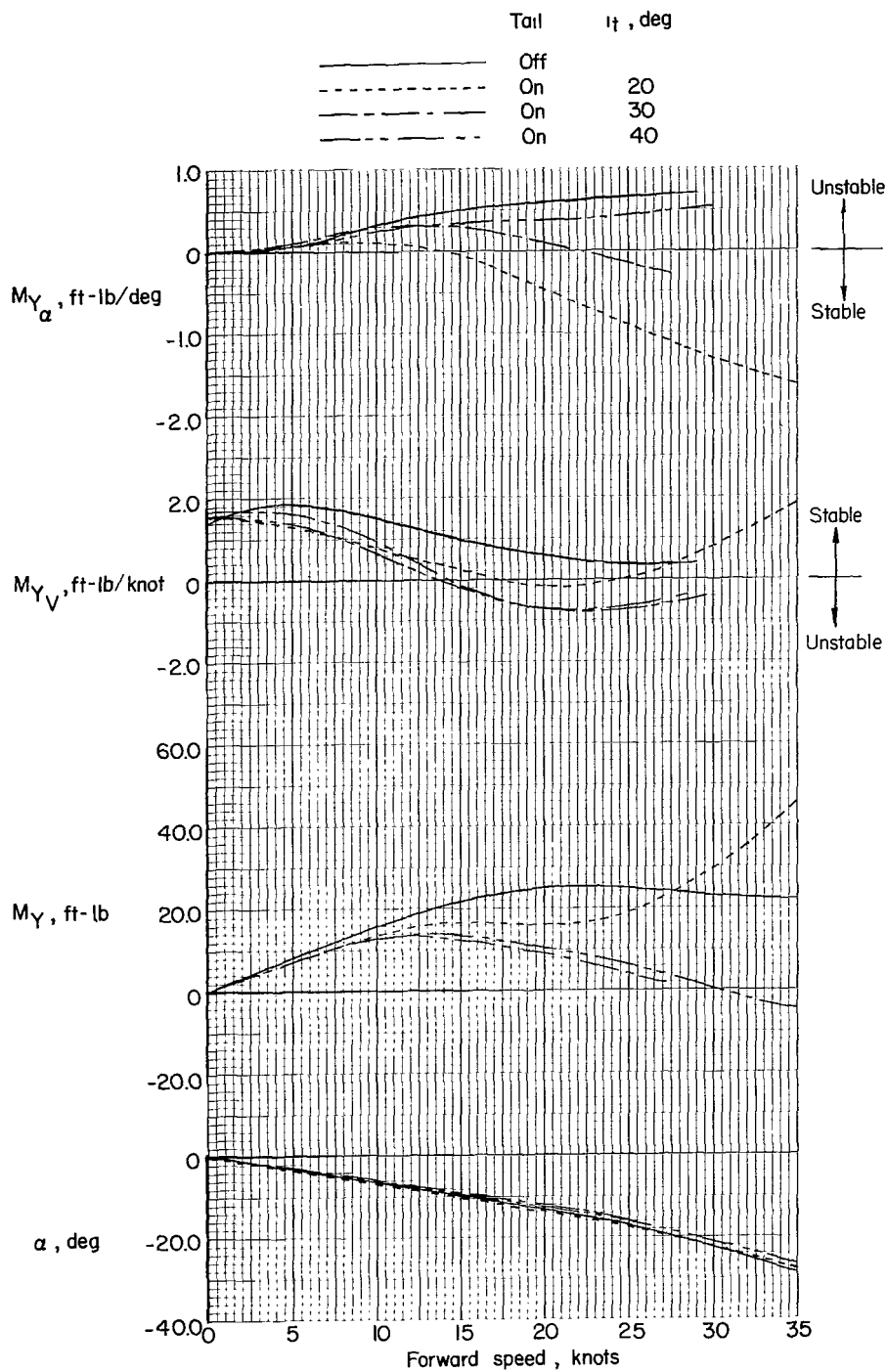
Figure 9.- Effect of horizontal tails on the longitudinal characteristics of configuration A.   Drag = 0.
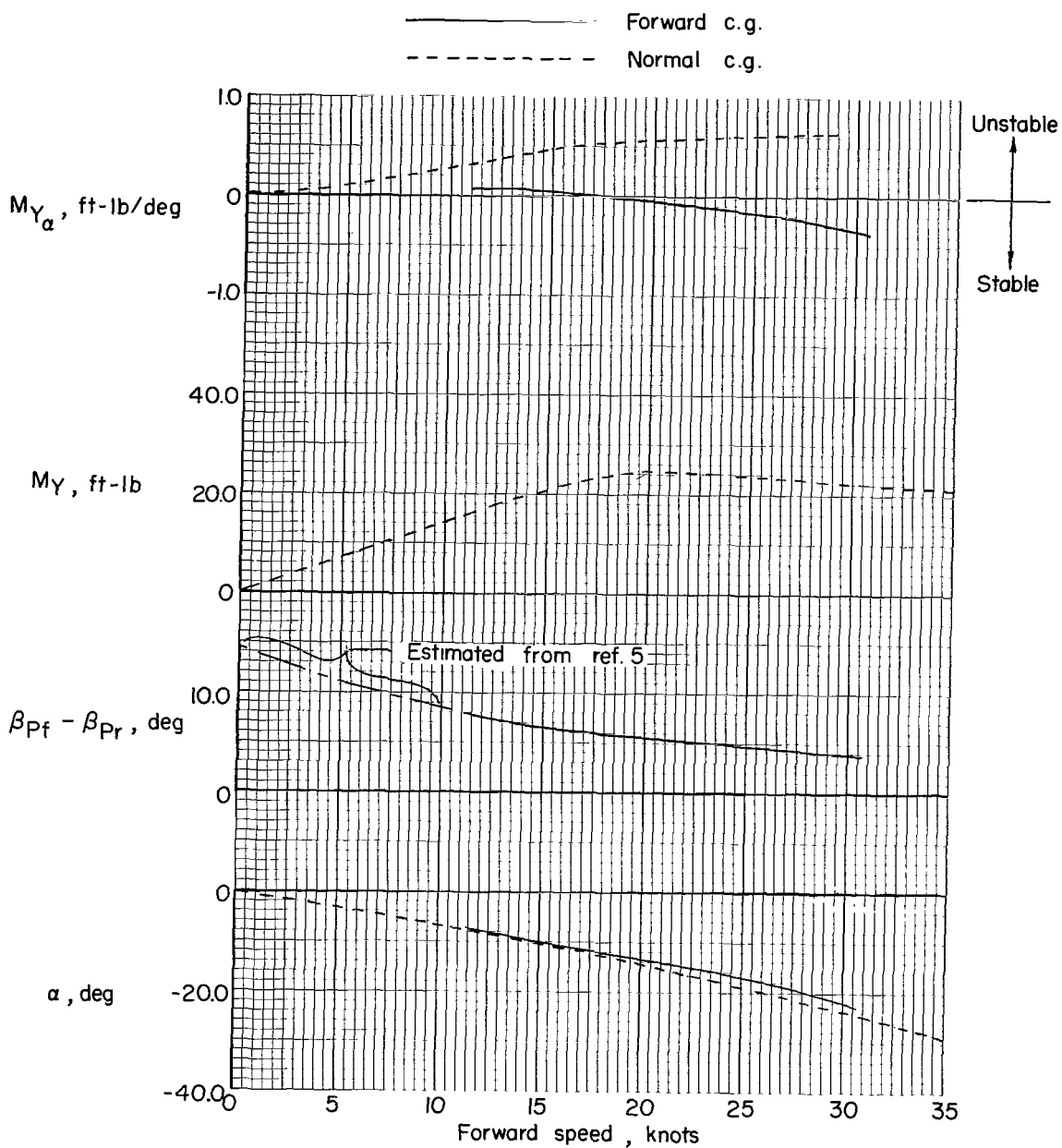
Figure 10.- Effect of horizontal tails on the longitudinal character-
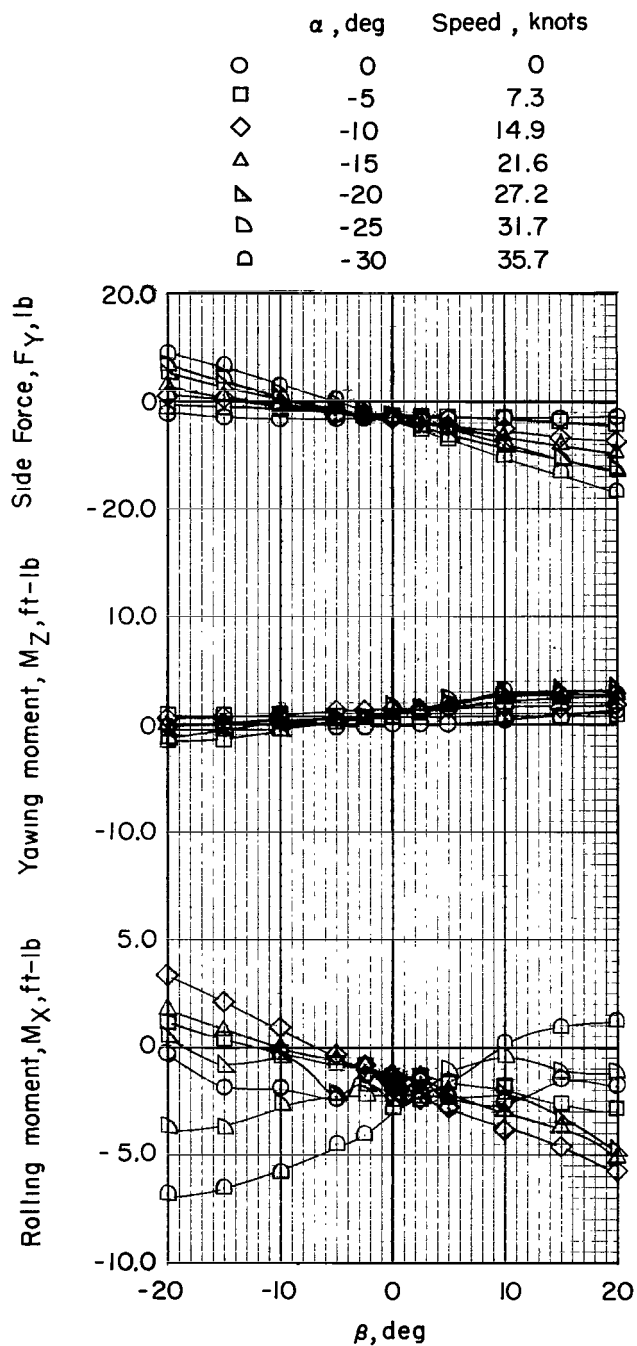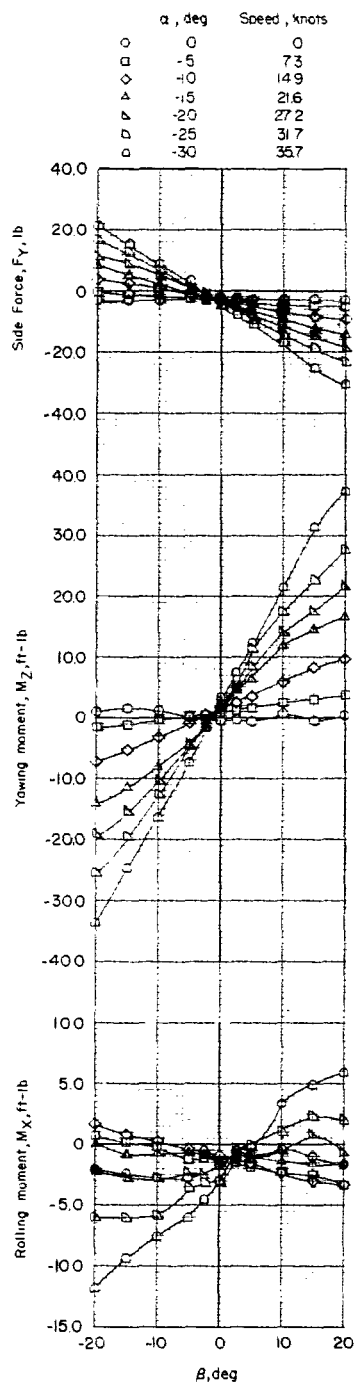istics of configuration B. Drag = 0.
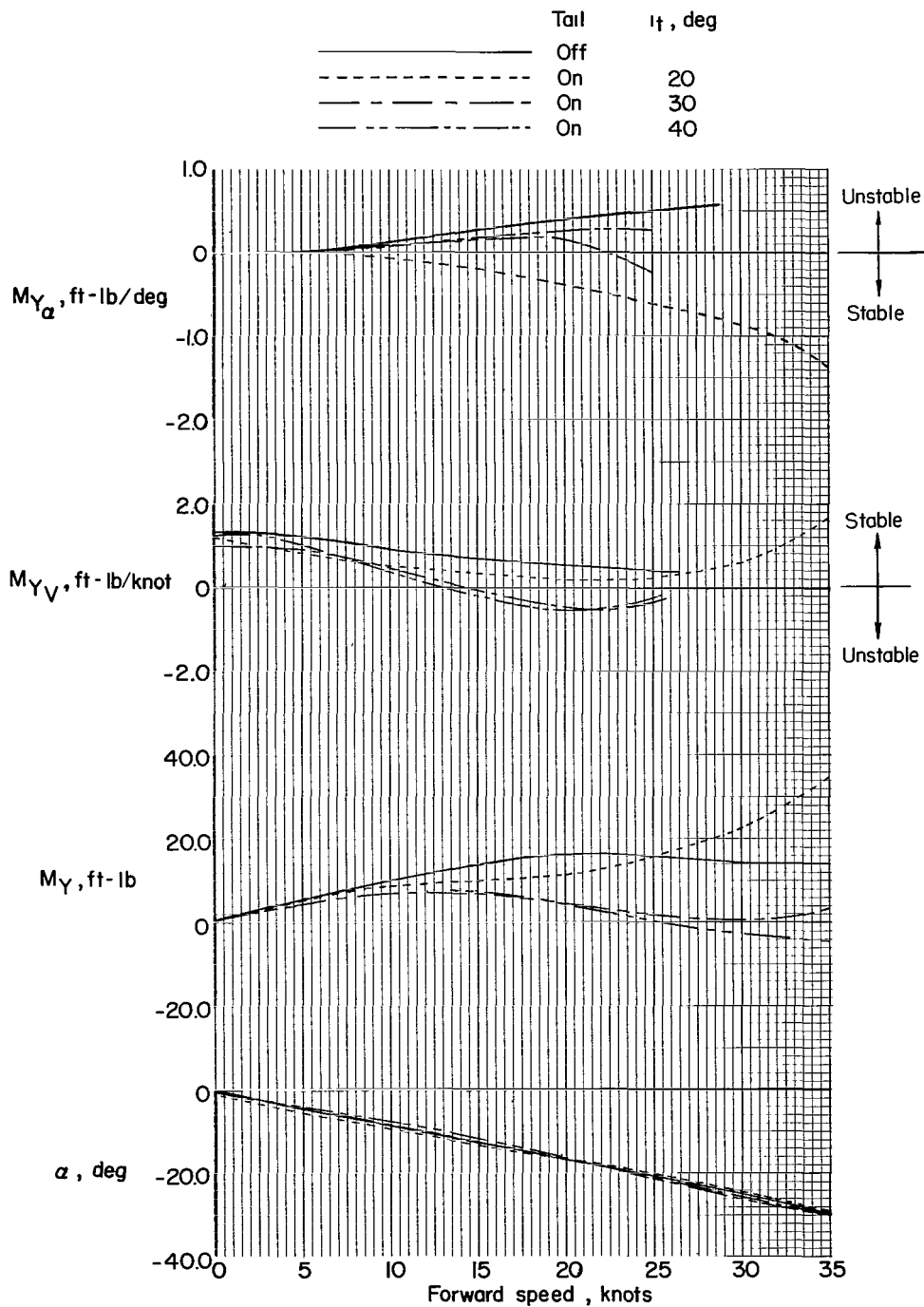
Figure 11.- Effect of forward center of gravity and differential propeller blade angle on the longitudinal characteristics of configuration A. No tails; drag = 0.
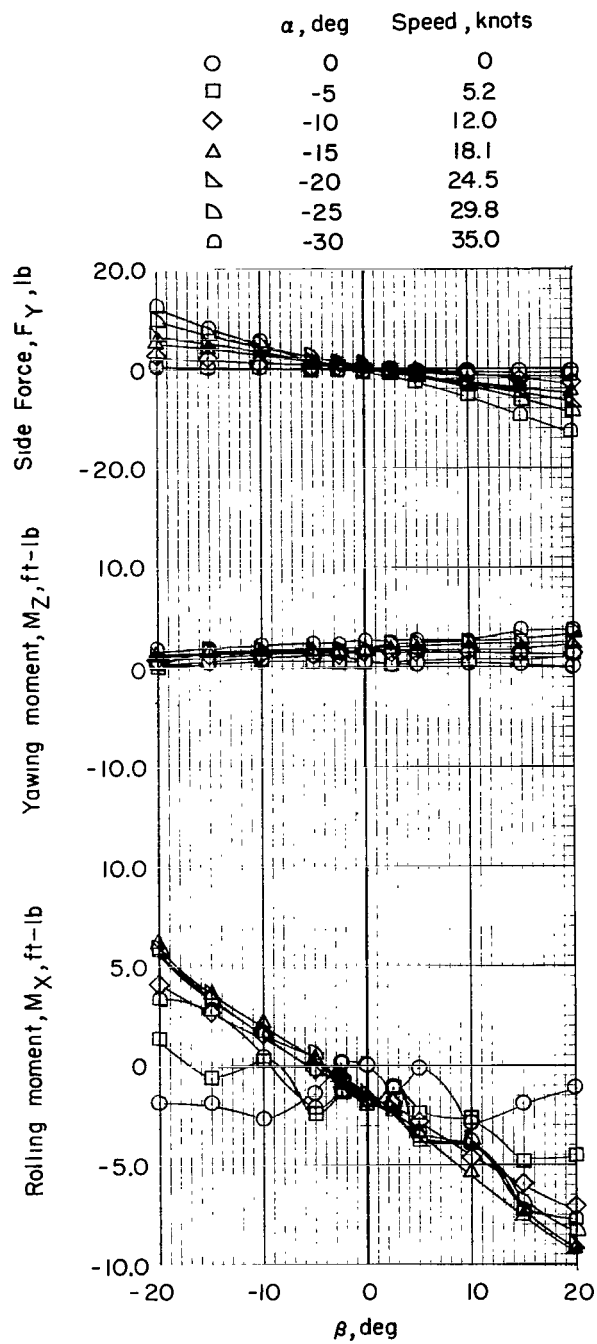
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	α, deg	Speed, knots
○	0	0
□	-5	7.3
◇	-10	14.9
△	-15	21.6
◁	-20	27.2
▷	-25	31.7
◻	-30	35.7

Side Force, F_Y, lb

Yawing moment, M_Z, ft-lb

Rolling moment, M_X, ft-lb

20.0

0

-20.0

10.0

0

-10.0

5.0

0

-5.0

-10.0

-20   -10   0   10   20

β, deg

(a) No tails.

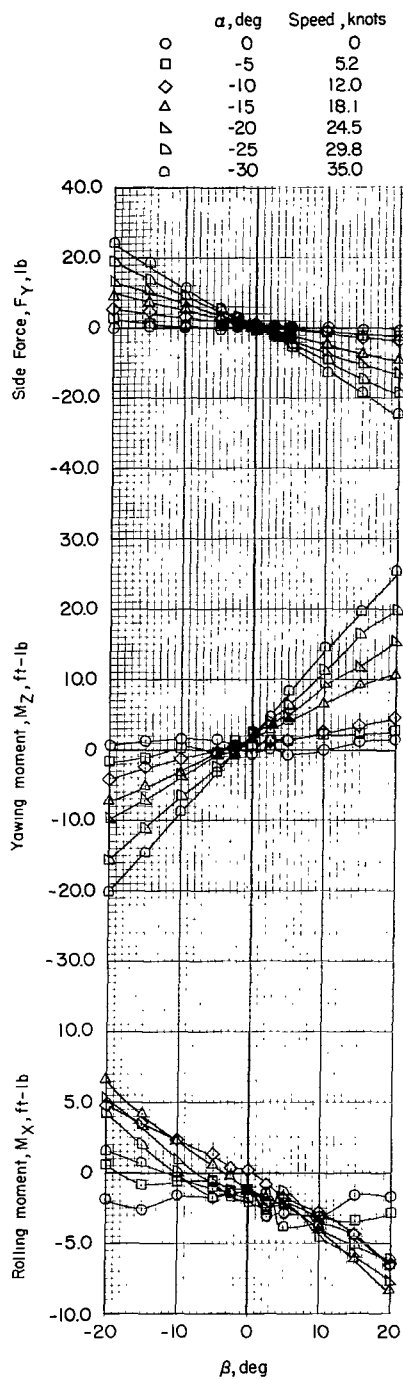Figure 12.- Basic lateral data, configuration A.   Drag = 0   at $\beta = 0^{\circ}$.
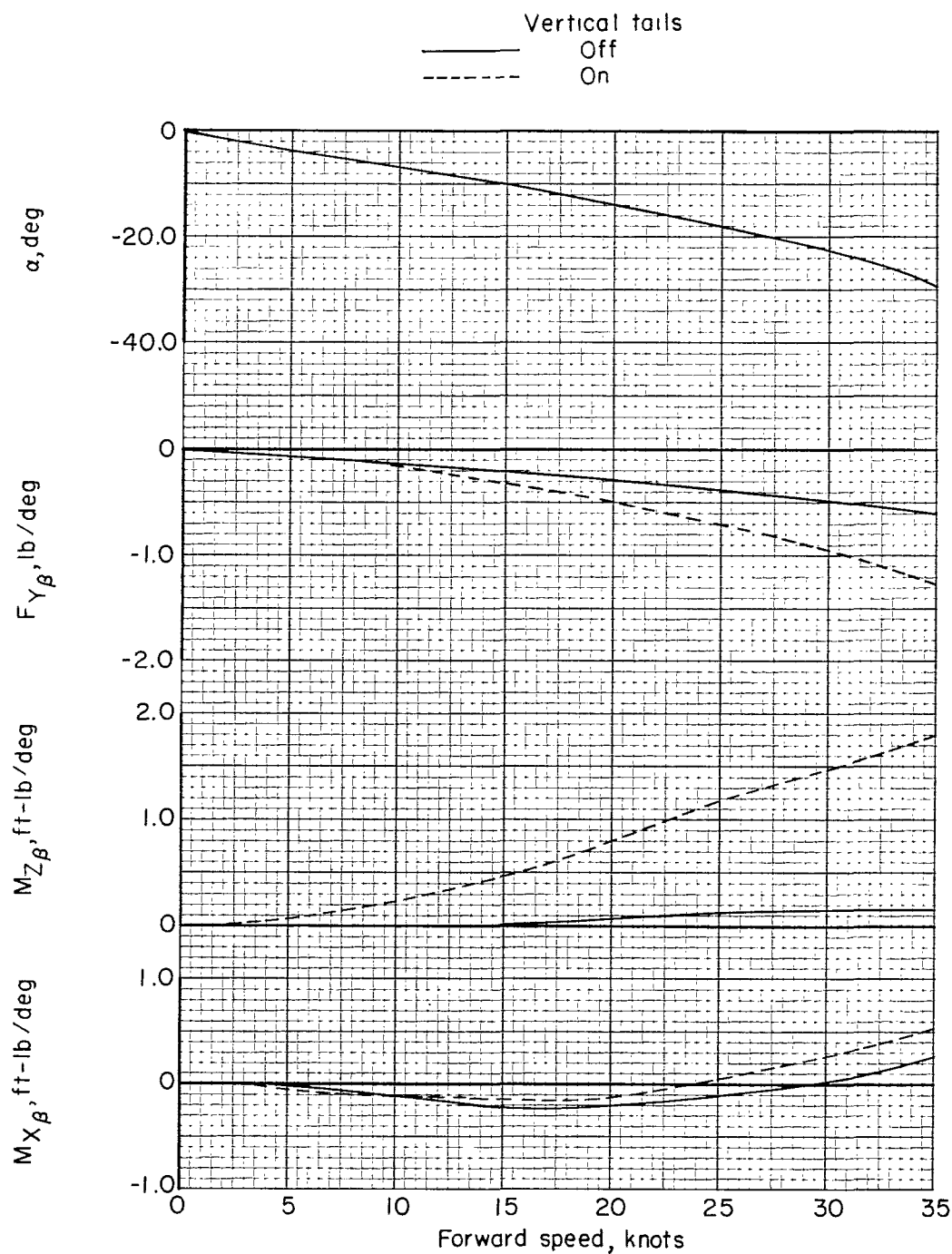
(b) Vertical tails on.

Figure 12.- Concluded.

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(a) No tails.

Figure 13.- Basic lateral data, configuration B.   Drag = 0   at $\beta = 0^{O}$.

	α, deg	Speed, knots
○	0	0
□	-5	5.2
◇	-10	12.0
△	-15	18.1
◁	-20	24.5
▷	-25	29.8
◻	-30	35.0

(b) Vertical tails on.

Figure 13.- Concluded.

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Figure 14.- Variation of lateral characteristics with forward speed for configuration A with and without vertical tails. Drag = 0 at $\beta = 0^{\circ}$.
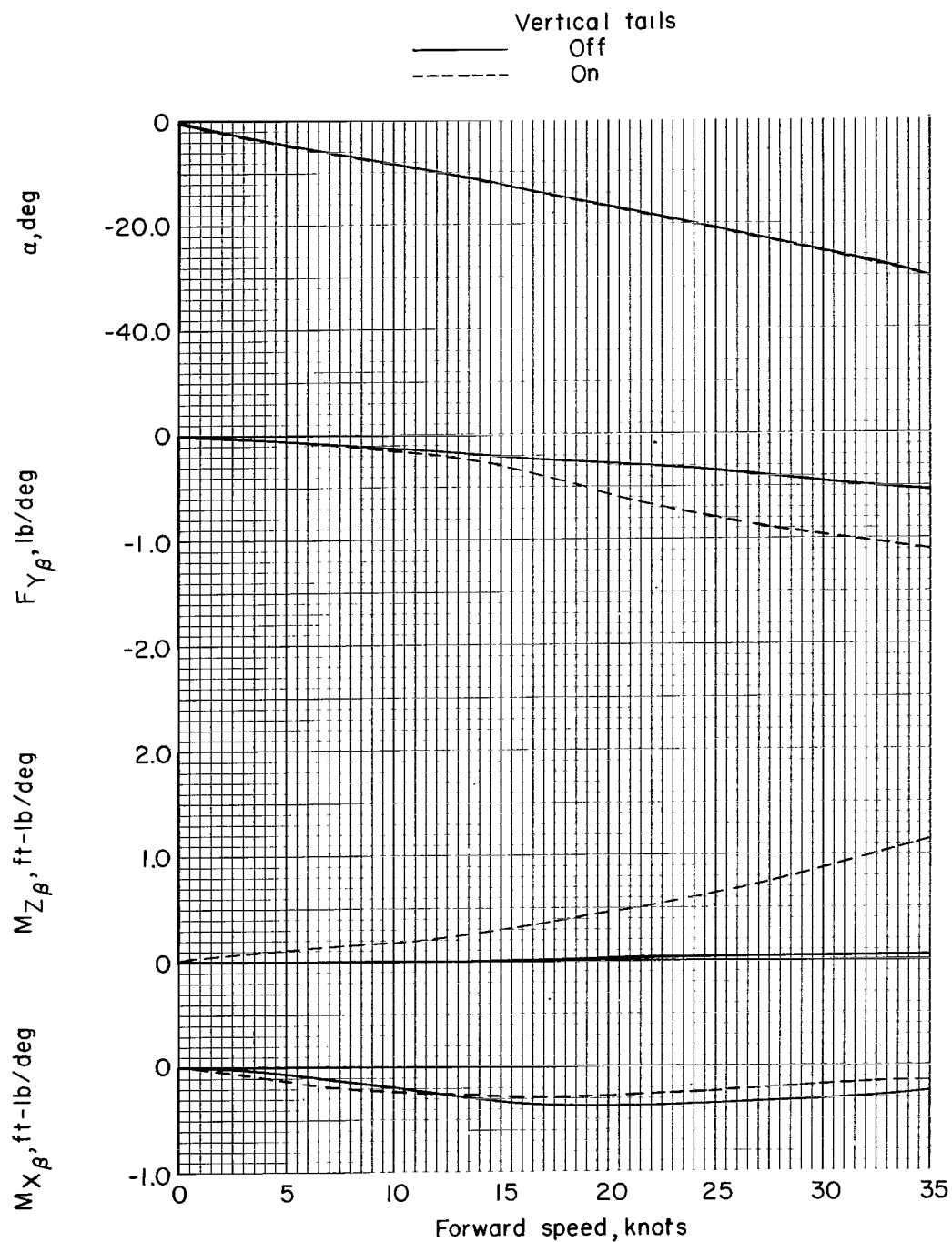
Figure 15.- Variation of lateral characteristics with forward speed for configuration B with and without vertical tails. Drag = 0 at $\beta = 0^{\circ}$.
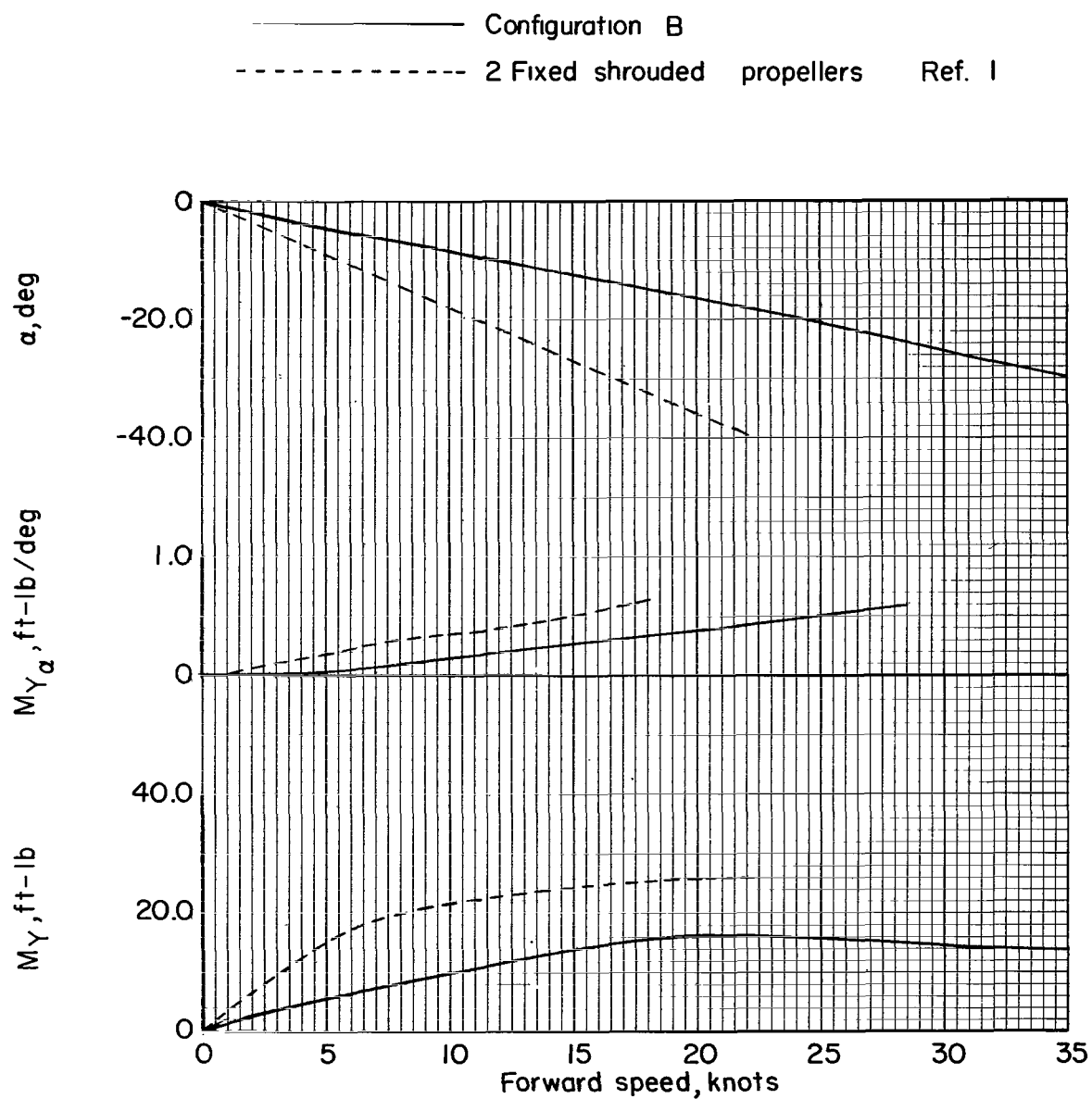
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Figure 16.- Comparison of longitudinal characteristics of config-
uration B without tails with shrouded-propeller configurations.
Drag = 0.